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16. Abstract  For many years, various apparatus and methods have been used for the expressed purpose of measuring and certifying the mesh conformance of fine sieves - primarily those sieves used by various highway agencies for the determination of aggregate material content and consistency.  Development of an Optical Sieve Comparator was undertaken by the Arizona Department of Transportation and the Optical Science Center at the University of Arizona in an effort to determine a practical and accurate method for the measurement and certification of sieve conformance to AASHTO M-92 specifications. The described comparator has proven highly successful in principle, as well as implementation. The comparator features: (1) Measurement of a wide range of mesh sizes (3/8" to No. 400); (2) GO/NO GO sampling for spotcheck statistical certification; (3) Absolute measurement; (4) Simple calibration procedures; (5) Variable optical path distance for wide range magnification; (6) Folded optical path; (7) Visual resolution and repeatability to 1.5 microns; (8) Individual precision viewing reticles for each sieve mesh size; (9) Rapid and convenient operation.					
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# OPTICAL SIEVE COMPARATOR DEVELOPMENT PROJECT

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## IMPLEMENTATION STATEMENT

Development of an Optical Sieve Comparator was undertaken by the Arizona Department of Transportation and the Optical Sciences Center at the University of Arizona in an effort to determine a practical and accurate method for the measurement and certification of sieve conformance to AASHTO M-92\* specifications. The described comparator has proven highly successful in principle, as well as implementation. The comparator features:

- Measurement of a wide range of mesh sizes — 3/8 inch through No. 400 sieves.
- GO/NO GO sampling for “spot check” statistical certification.
- Absolute measurement capability.
- Simple calibration procedures.
- Variable optical path distance (21.5” to 33”) for wide range magnification.

- Folded optical path for a compact, portable design.
- Visual resolution and repeatability to 1.5 microns (40X lens).
- Individual, precision viewing reticles (GO/NO GO) for each sieve mesh size.
- Rapid and convenient operation.

The purpose of this report is to inform the various state and federal agencies as to Optical Sieve Comparator development and design efforts conducted by the Arizona Department of Transportation. Although development and basic design principles are presented, no attempt has been made to present actual construction detail. It is anticipated however, that upon reviewing the report, certain agencies may wish to develop and construct similar comparators for their own use. Should this be the case, those agencies are encouraged to contact and consult with the Arizona Department of Transportation, Research Division. Arrangements can be made for individual demonstration and consultation sessions at the ADOT facility, 206 South 17th Avenue, Phoenix, Arizona 85007.

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\*American Association of State Highway and Transportation Officials. *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, Part I — Specifications; M92-70, Standard Specification for Wire Cloth Sieves for Testing Purposes. NOTE: Equivalent to ASTM E-11-70.



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## INTRODUCTION

For many years, various apparatus and methods have been used for the expressed purpose of measuring and certifying the mesh conformance of fine sieves — primarily those sieves used by various highway agencies for the determination of aggregate material content and consistency.

Specification standards set down by AASHTO M-92 dictates requirements for the certification of fine mesh sieves. To meet these standards, various precision measurement methods are being used and are continuously being devised. The choice of a measurement method involves several considerations, including precision, ease of operation, reliability and others. However, of vital importance is the ability to accurately certify a large number of sieves, of varying mesh size, in a relatively short period of time. In addition, this certification should be accomplished by personnel of nominal skill level.

The Manual of Highway Materials, Part I, 10th Edition, as adopted by the American Association of State Highway and Transportation Officials, describes several contemporary methods of sieve certification in the Appendix to AASHTO M-92 (pages 103-104). These methods include split-image and micrometer microscopes, various contour projection systems and the much used Moire' effect.

The micrometer microscope, although highly accurate, has the disadvantages of being not only fatiguing and tedious, but extremely time consuming when performing a statistical sample of maximum and minimum openings within the sieve cloth. Although time consuming, the microscope is highly reliable in measuring wire diameters and determining the number of wires per centimeter.

The split-image microscope is a high quality, extremely delicate device, but again, is both tedious and time consuming for sieve certification applications.

The Moire' effect, a generally used measurement method, is based on optical diffraction phenomena. This phenomena is caused by the formation of a two-dimensional grid when a precision ruled glass scale is placed onto the surface of the wire cloth. The Moire' effect, as detailed in the ASTM, E11 Appendix, paragraph A1.13, can effectively be used as a means of determining mesh count (number of wires per centimeter) and wire diameter. Interference fringes between two beams of monochromatic light (light of a single wavelength) have long been used for highly refined and precise measurement of length. When performing measurements by this method, length is determined in terms of the



wavelength of the particular light source being used. Measurement order of magnitudes of 20 micro-inches are possible, although only rarely required in most laboratory work.

It is possible, however, to produce Moire' fringes with "white" light by the use of two coarse slit-and-bar gratings. These consist of glass plates on which opaque bars are ruled at regular intervals — leaving transparent slits of equal width. If two such gratings are face-to-face super-imposed with their rulings nearly parallel, and viewed on a diffused light background, sharp Moire' fringes will be observed. Appendix A provides a more detailed analytical explanation of the Moire' pattern as formed by parallel gratings of slightly different pitch.

The Moire' effect has widespread application in the technology of measurement, primarily in the science of strain analysis, the study of surface topology, and stress and strain analysis as applied to deflections in flexed structures.

Application of the Moire' effect to the measurement and certification of a large number of sieves is a legitimate approach, but, not unlike the microscope, is found to be a tedious and highly sophisticated method of measurement — requiring the use of experienced high-skill personnel.

In 1922, the National Bureau of Standards developed a projection apparatus which was intended primarily for the testing of sieves in general.\* The projection system developed by the Bureau was found to be much faster and less fatiguing to the operator. They found by experience that in testing sieves for conformity to the "Standard Specification for Sieves," the most reliable results were obtained by measuring the wire diameters and determining the number of wires per centimeter. The mesh opening was then determined by the following formula:

$$D = \frac{10}{N} - W$$

where D = Average mesh opening in millimeters  
N = Number of wires per centimeter  
W = Average wire diameter in millimeters

Measurements were taken on any number of the warp and the shoot wires of the cloth. The cloth could also be examined for "maximum" openings. It was found that the projection system allowed

measurements in a fraction of the time normally required by the various other optical systems. The NBS projection system was by definition an optical comparator, utilizing a projected image of the sieve screen onto a ground glass plate — then measuring the calibrated projected image of the openings by way of a steel rule. For a more detailed description of the NBS sieve comparator, refer to Appendix B. In addition, Appendix C offers an NBS comparator application intended for the precision measurement of the coating thickness of corrosion protected iron screw threads. It should be noted that the NBS comparators did emphasize one vital aspect — that is, its speed and accuracy of measurement was clearly of major importance when a large number of sieves (or other objects) are to be examined in a relatively short period of time. The comparator (projection) concept also allows a truly comprehensive evaluation of each sieve, consistent with AASHTO standards.

The NBS comparator was state-of-the-art in the late 1960's when the Arizona Department of Transportation undertook the challenge to research, design and build an optical comparator system specifically for the measurement and certification of the full range of sieves in use. Many features were to be considered. Of prime importance was the use of an adjustable folded mirror optical path. By folding the optical path, a large optical distance could be achieved within a small physical space. This long (adjustable) optical distance would allow the use of multiple interchangeable lens systems to accurately and conveniently cover the full range of magnification required for various sieve sizes. Also, in conjunction with the University of Arizona, a specially designed, highly efficient illumination system was constructed which would be compatible with the full range of lenses used.

In addition, special telecentric lenses were used. With these lenses, the magnification of an object remains "constant," independent of focus. This important feature allowed the focus to be optimized for a sharp image during the various sieve measurements without influencing optical calibration.

Of special interest was the requirement that the comparator be capable of not only absolute measurements over a wide range of sieve mesh openings (Number 8 through 200), but be fully adapted to perform GO/NO GO certification by the use of calibrated viewing reticles. The GO/NO GO concept, in conjunction with the Fisher Sign Test, allows the operator to rapidly scan each sieve and determine any variance from the specified tolerance as set

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\*Department of Commerce Bureau of Standards. *Letter Circular* LC-72 (July 26, 1922). Also see LC-584 (March 1, 1940).



down by AASHTO and ASTM. This very rapid statistical sampling allows all sieves to be certified on a regular and continuing basis.

The Optical Sieve Comparator represents the culmination of a great amount of effort, involving planning, the building of prototypes and the analysis of performance. The results have been highly successful and rewarding for all participating individuals. You will find that the ADOT Comparator has met its goals — that is, to determine and implement a practical and accurate method for the measurement and certification of sieve conformance to AASHTO M-92 specifications. As the result, the ADOT Comparator features:

- Measurement of a wide range of mesh sizes — 9.5mm to 0.075mm nominal opening size. (3/8 inch through No. 400 sieves.)\*
- GO/NO GO Sampling for “spot check” statistical certification
- Absolute measurement capability

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\*The “number” designation refers to the number of openings per linear inch, e.g., the No. 40 sieve has 40 openings per linear inch. Metric sizes are now the official method of measurement or designation.

- Simple calibration methods
- A variable optical path. distance (21.5 to 33 inches) for wide range magnification
- A folded optical path for a compact, portable design
- Visual resolution and repeatability to 1.5 microns (40X lens)
- Individual, precision reticles (GO/NO GO) for each sieve size
- Rapid and convenient operation

The purpose of this report is to inform the various state and federal agencies as to the Optical Sieve Comparator developments and design efforts conducted by the Arizona Department of Transportation (ADOT). Although development and fundamental design principles are presented, no attempt has been made to present actual construction detail. It is anticipated however, that upon reviewing the report, certain agencies may wish to develop and construct similar comparators for their own use. Should this be the case, those agencies are encouraged to contact and consult with the ADOT Research Division. Individual demonstrations and consultation sessions can be arranged at the ADOT facility.





## OPTICAL SIEVE COMPARATOR A DEVELOPMENT PROJECT

### DESIGN CRITERIA

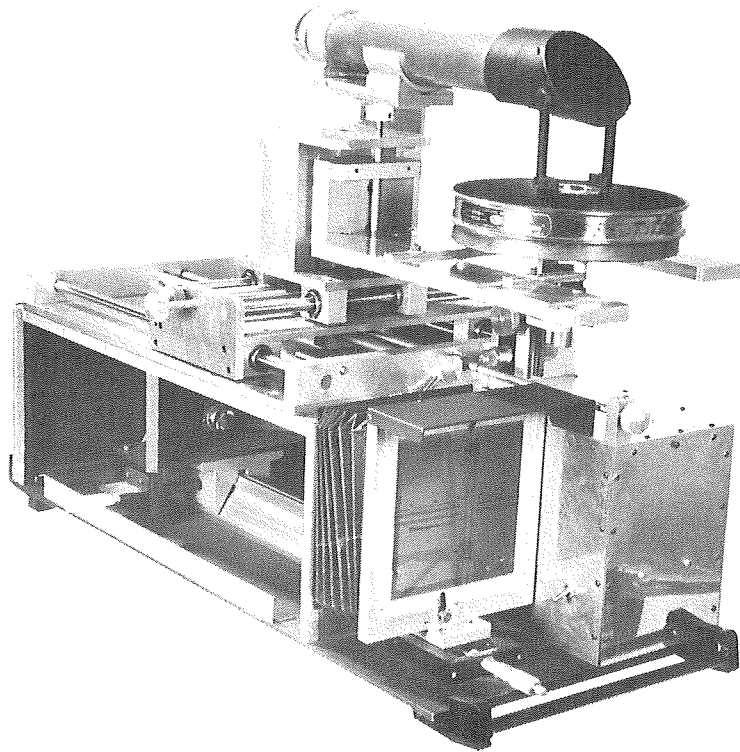
Before proceeding with basic design considerations, the ADOT research team spent many hours evaluating existing techniques that were currently in use by other highway agencies. This investigation revealed various methods — mostly including optical comparison, the micrometer microscope, the Moire' effect principle and others as previously described in the Introduction to this report. Two basic conclusions were evident — (1) Optical projection comparators were not being utilized, primarily due to the absence of commercially available systems which could be adapted to the sieve application, and (2) those techniques currently in use by most agencies were exceedingly time consuming and tedious. This being the case, it was found that agencies were very often and routinely using sieves of unknown quality.

This lack of certification is somewhat understandable when considering that the referee test for a single sieve requires that up to 300 sieve openings be measured in order to comply with AASHTO M-92 specifications. To further compound this very tedious task, ADOT experience has found that for a reliable evaluation, each single sieve opening must include four (4) vertex-to-vertex measurements

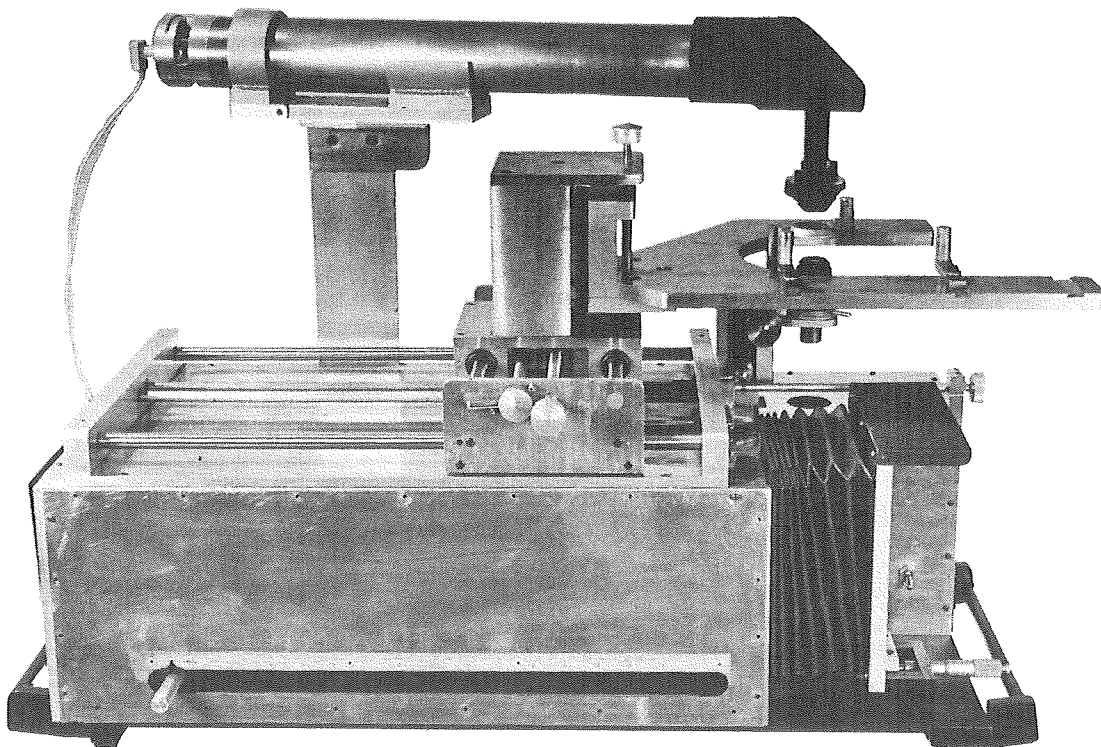
around the perimeter of the opening.

With the determination that the ADOT developed apparatus would consist of an optical projection comparator, a design specification was developed with the following objectives:

1. The optical system would have a light path of variable distance (i.e., variable optical length).
2. Optical mirrors would be employed to "fold" the light path — allowing compact design and portability.
3. The system must be easily calibrated by use of visual optical methods (i.e., by use of a precision calibration viewing reticle and reference standard).
4. The system must be capable of absolute measurement of wire diameters and mesh openings.
5. A GO/NO GO system of sieve evaluation to allow rapid and comprehensive certification of all sieve sizes.
6. Must be capable of evaluating a wide range of sieve sizes — from Number 8 to Number 200.
7. Finally, the comparator system must be designed for operator convenience, with precision controls for sieve position and focus adjustment.



**Figure 1A. Opticle Sieve Comparator**



**Figure 1B. Opticle Sieve Comparator**

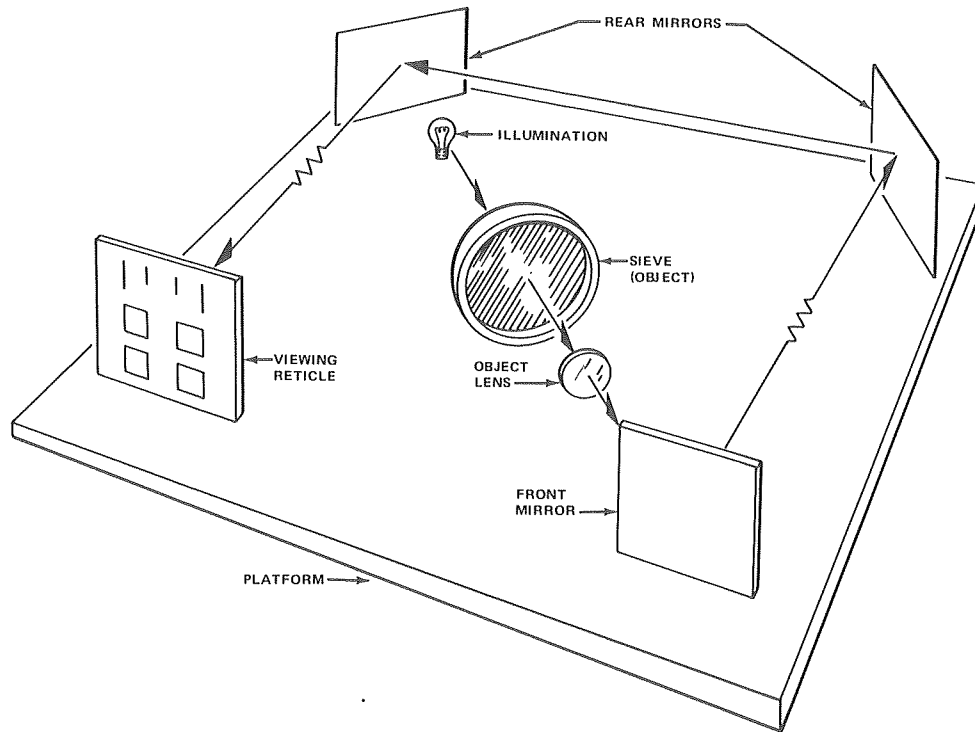


Figure 1C. Schematic of Comparator Operation

## GO/NO GO TESTING

As indicated in the above objectives, a primary and very vital design function of the ADOT comparator was its ability to perform GO/NO GO evaluation of sieve sizes ranging from No. 8 to No. 200. In addition, the GO/NO GO feature must maintain precision comparable to existing optical instruments (micrometer microscopes, etc.).

In the evaluation of any sieve, the objective is the observation of mesh openings and the determination of any variance from specified tolerances as set down by AASHTO and ASTM.\*

The GO/NO GO concept is a method of comparison whereby a projected image of a sieve opening is projected upon a screen which contains precision squares, each drawn according to mesh opening specifications as set down by AASHTO and ASTM (see Figures 2 and 3). The image of an opening can then be super-imposed upon each of the four squares. The square sizes correspond to tolerances as given in Table 1.

During GO/NO GO testing, the operator uses a method developed by ADOT. This method allows the operator to keep track of the test results by means of a control chart as shown in Figure 4. In this way, the results can be evaluated as testing proceeds. The actual values contained in these charts are based on the Binomial Distribution and the operator's choice of confidence level. Thus, the operator automatically performs a statistical test of hypothesis as he proceeds with the evaluation.

Testing at ADOT has shown that the above method proceeds at a rate of 2/3-minutes per opening, with a 5-minute set-up time for each sieve size.

## THE COMPARATOR ASSEMBLY

### Housing Assembly

The ADOT comparator, as shown in Figure 5, consists of an optical "V"-rail mounted to a stable 13 x 30 inch platform.\* The V-rail assembly is enclosed within a box-like housing with a height of 8 inches. The rail platform and housing are machined of

\*American Society for Testing Materials, *Annual Book of ASTM Standards*, Part 41. Ref. E-437-77, Standard Specifications for Industrial Wire Cloth and Screens; E-161-70, Standard Specifications for Electroformed Sieves (The primary standard is ASTM E-11).

\*The reader who wishes to construct a duplicate comparator must deal with a mixture of both English and Metric units. Optical parts are referred in Metric units, while construction dimensions, etc. are in English units to be consistent with most machine shop standards.

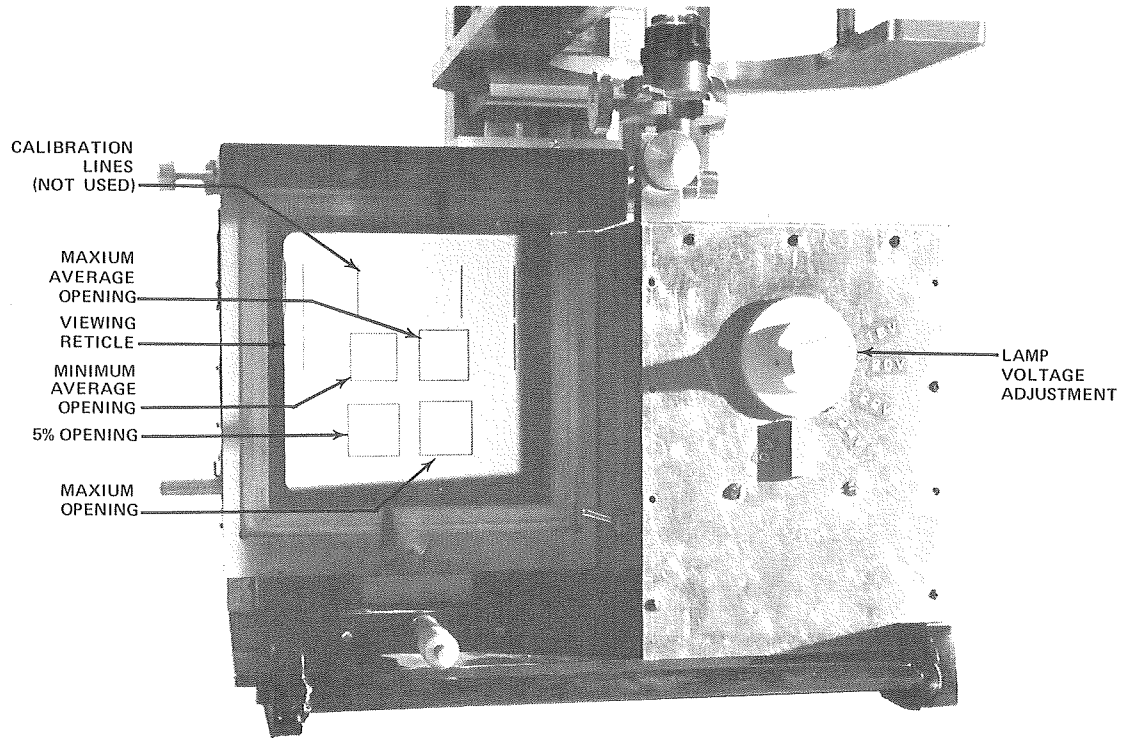


Figure 2. Viewing Reticle Pattern For Go/No Go Testing

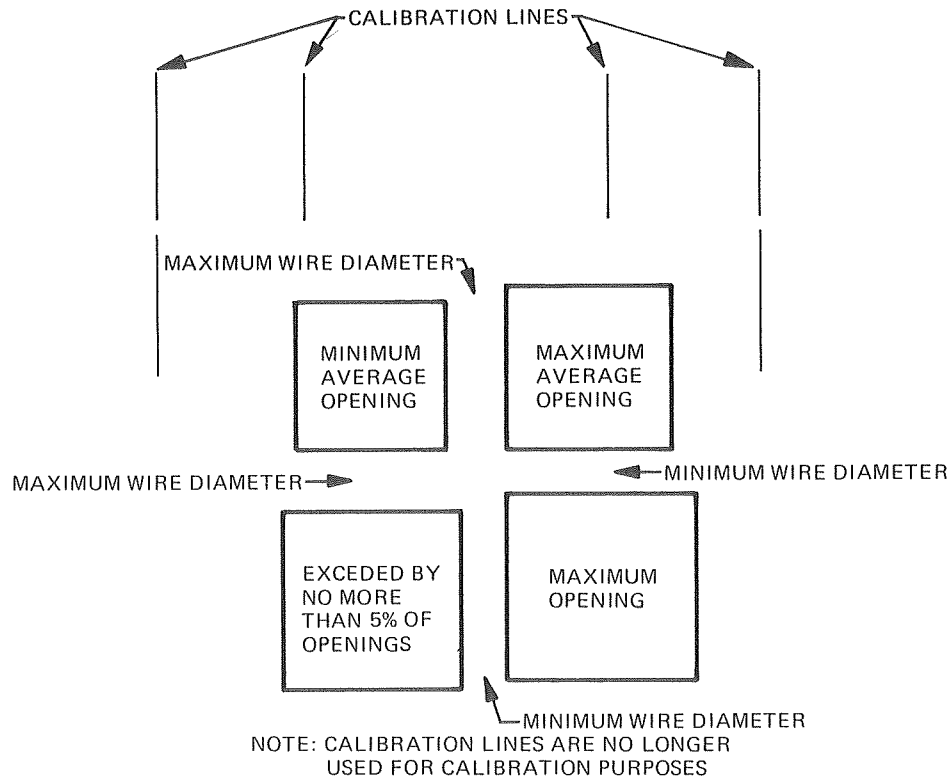


Figure 3. Sieve Evaluation Reticles



5%	59	1	7	16	28	40	53	REJECT								
LARGE		9	12	15	17	20	23	25	28	30	33	35	37	40	42	44
SMALL		9	12	15	17	20	23	25	28	30	33	35	37	40	42	44
TOTAL		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Acceptance  $\alpha = 0.025$  for large and small sizes.  
Rejection  $\alpha = 0.050$  for each category.

5%																
LARGE	23	24	26	28	30	31	33	35	37	39	40	42	44	45	47	
SMALL	23	24	26	28	30	31	33	35	37	39	40	42	44	45	47	
TOTAL	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	

5%																
LARGE	49	51	53	54	56	58	60	REJECT								
SMALL	49	51	53	54	56	58	60	REJECT								
TOTAL	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	

Figure 4. Sieve Evaluation Chart

heavy gauge aluminum to form a rigid structure for the mounting of all remaining optical sub-assemblies.

#### Object Translator Carriage Assembly

The upper surface of the housing provides mounting for the sieve (object) translator carriage and the lens mount assembly (Figure 6). The sieve carriage assembly is attached to the housing by way of two (2) precision ball-slides and a full length lead-screw. The lead-screw allows the operator to position the sieve carriage in the longitudinal ("Y") direction. This longitudinal adjustment is a "fine" adjustment with a full range of 10.5 inches. A coarse adjust lever allows the lead-screw to be disengaged for "hand" positioning the carriage over its full range (coarse adjustment).

For transverse ("X") adjustment (side-to-side), a sieve holder assembly (object table) is mounted to the carriage by way of two (2) transverse ball slides. Transverse adjustment is provided by a "fine" adjust lead-screw, having a total travel of 7.5 inches. A coarse adjust lever disengages the lead-screw, allowing the sieve holder to be "hand" positioned over the full transverse range (Figures 5 and 6).

Vertical ("Z") positioning of the sieve holder is by "fine" adjust lead-screw without disengage capability. The vertical adjustment range is 1.5 inches.

The three sieve positioning adjustments as described above, provide the following functions:

1. The longitudinal (Y) and transverse (X) adjustments are used by the operator during sieve evaluation — allowing precise positioning of individual mesh openings or wire images relative to the measurement of GO/NO GO viewing reticles.
2. The vertical (Z) adjustment is used to focus the light source (filament) on the object for maximum intensity during protection. It should be noted that the Z-adjustment is the only focusing adjustment, or adjustment at object position allowed after system calibration. This being the case, this adjustment is used only for re-focusing or maximizing light intensity during sieve evaluation.

The horseshoe shaped sieve holder (Figures 5A and 6A) serves as a mounting surface for the sieve during sieve evaluation, and as a support for the plexiglass calibration plate during system calibration. Three adjustable sieve support posts support the sieve or calibration plate during operation.

#### Objective Lens Mount Assembly

Also mounted to the comparator housing support surface is the lens mount assembly (Figure 7). Note that the assembly has two (2) lens mounts (upper and lower) for mounting the various objective lens, with each lens providing a different magnification range (See Table 2). The upper mount accepts the



**TABLE 1**  
**SPECIFICATION FOR MATERIALS (AASHTO M92)**

Nominal Dimensions, Permissible Variations for Wire Cloth of Standard Test Sieves (U.S.A. Standard Series)					
Sieve Designation		Permissible Variation of Average Opening from the Standard Sieve Designation mm	Maximum Opening Size for not more than 5 per cent of openings mm	Maximum Individual Opening mm	Nominal Wire Diameter mm
Standard mm	Alternate				
(1)	(2)	(4)	(5)	(6)	(7)
4.75	No. 4	0.15	5.02	5.14	1.54
2.36	No. 8	0.080	2.515	2.600	1.00
2.00	No. 10	0.070	2.135	2.215	0.900
1.18	No. 16	0.045	1.270	1.330	0.650
0.850	No. 20	0.035	0.925	0.970	0.510
0.600	No. 30	0.025	0.660	0.695	0.390
0.425	No. 40	0.019	0.471	0.502	0.290
0.300	No. 50	0.014	0.337	0.363	0.215
0.150	No. 100	0.008	0.174	0.192	0.110
0.075	No. 200	0.005	0.091	0.103	0.053
0.045	No. 325	0.003	0.057	0.066	0.030
0.038	No. 400	0.003	0.048	0.057	0.025

Column (3) omitted

**TABLE 2**  
**OBJECTIVE LENSES**

Objective Type	Magnification Range	Working Distance (mm)	Linear Field Of View (mm)	
X3	8-24	60	10-20	} Lower Mount
X5	10-30	45	8-11	
X10	25-75	7	5-6	} Upper Mount
X20	50-150	2	4	
X40	100-300	1	2	

Objective lenses and their performance parameters. Note change of field of view with magnification for lower power lenses.

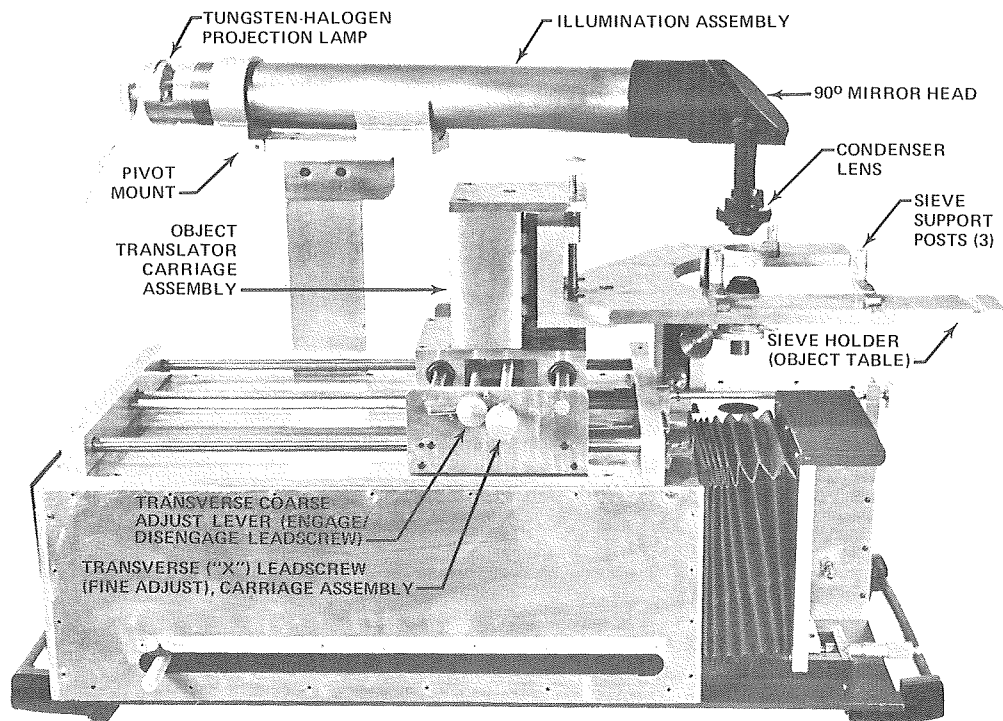


Figure 5A. ADOT Comparator — Detail View

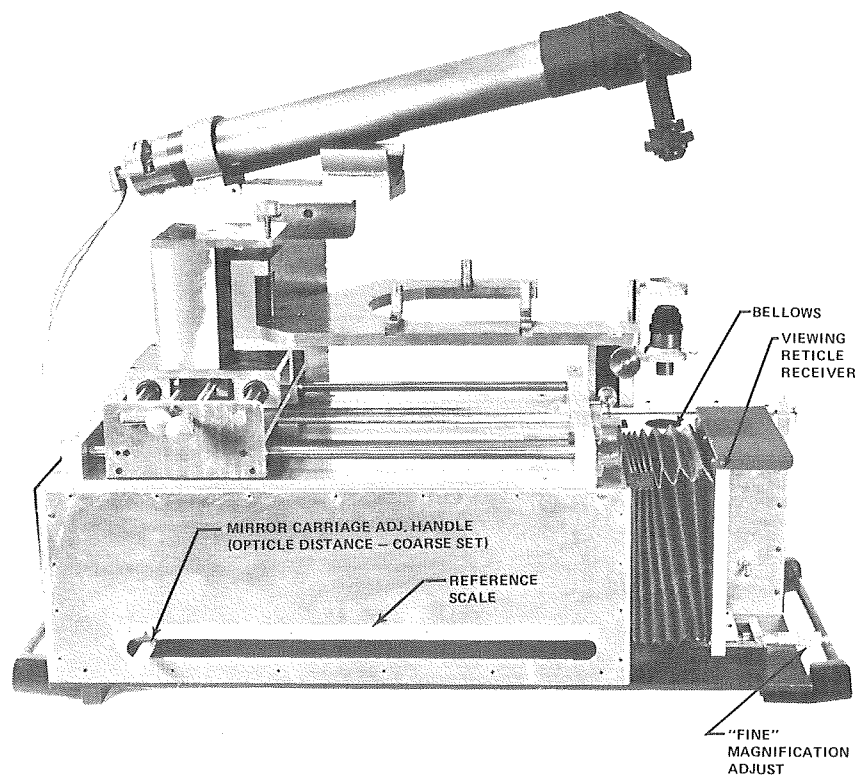


Figure 5B. ADOT Comparator — Detail View

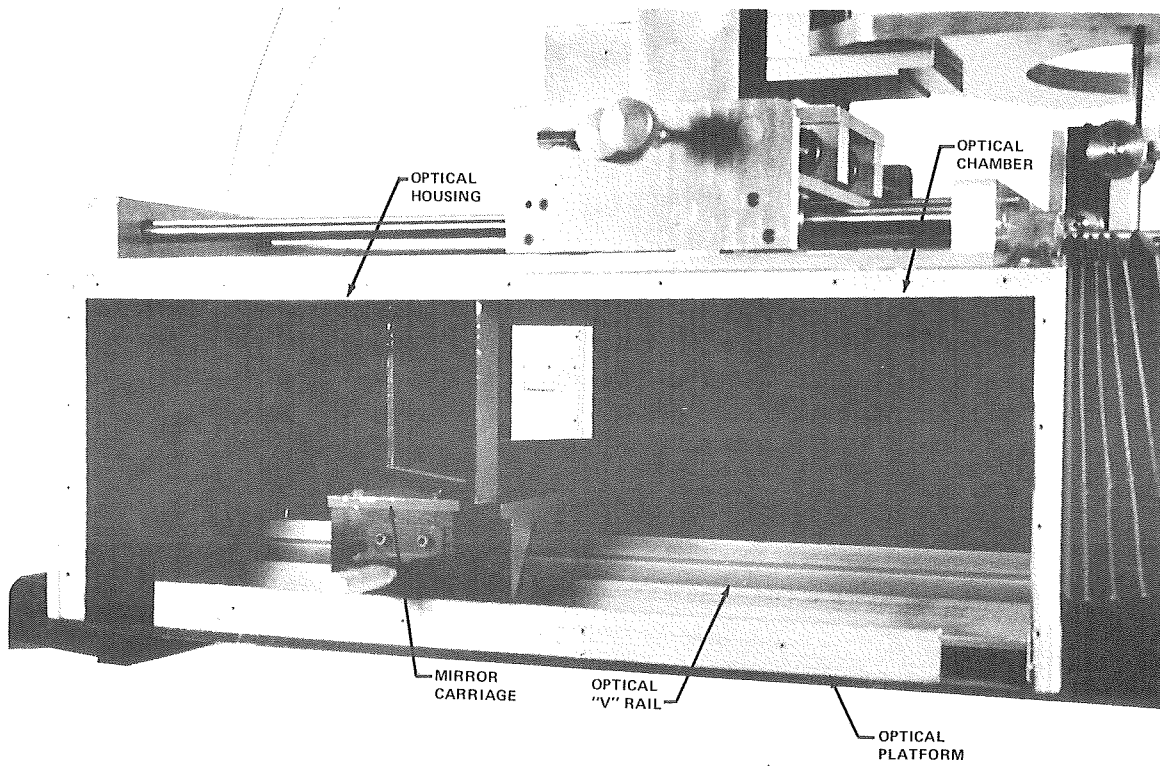


Figure 5C. ADOT Comparator — Detail View

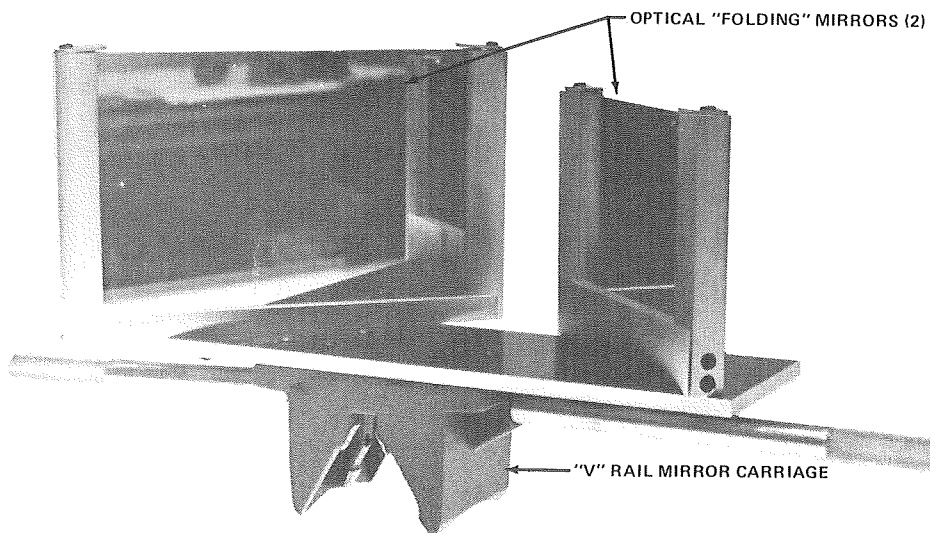


Figure 5D. ADOT Comparator — Detail View

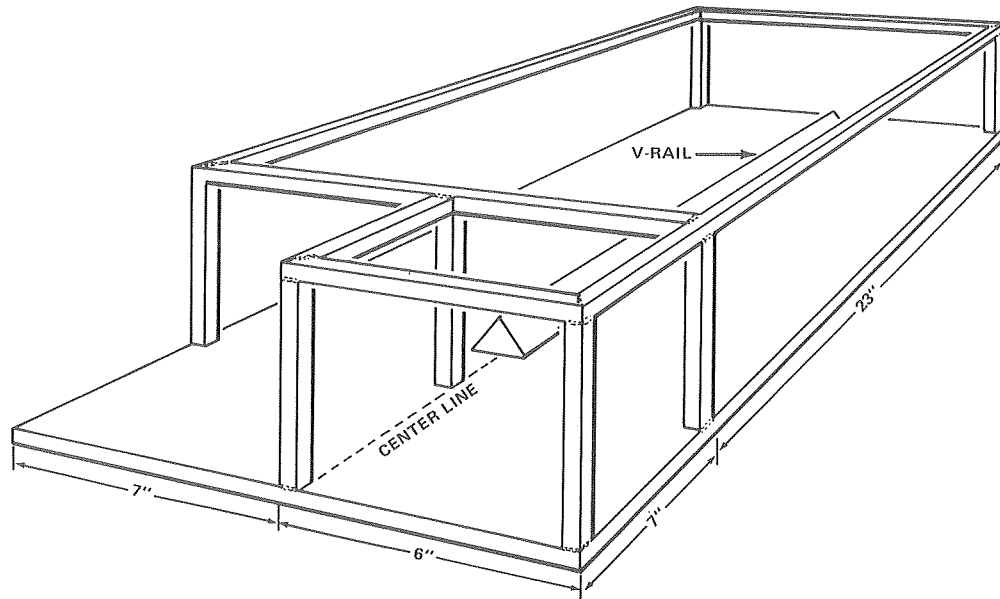


Figure 5E. Comparator Platform, V-Rail Housing

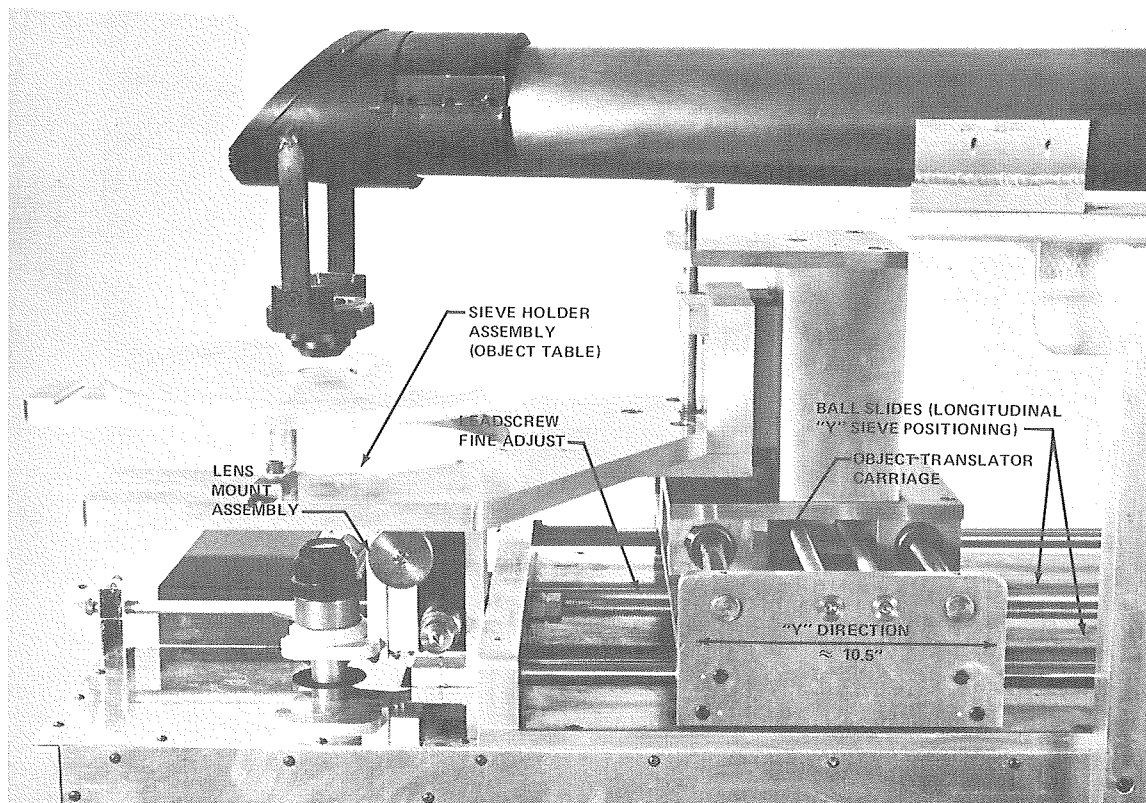


Figure 6A. Object Translator Carriage Assembly

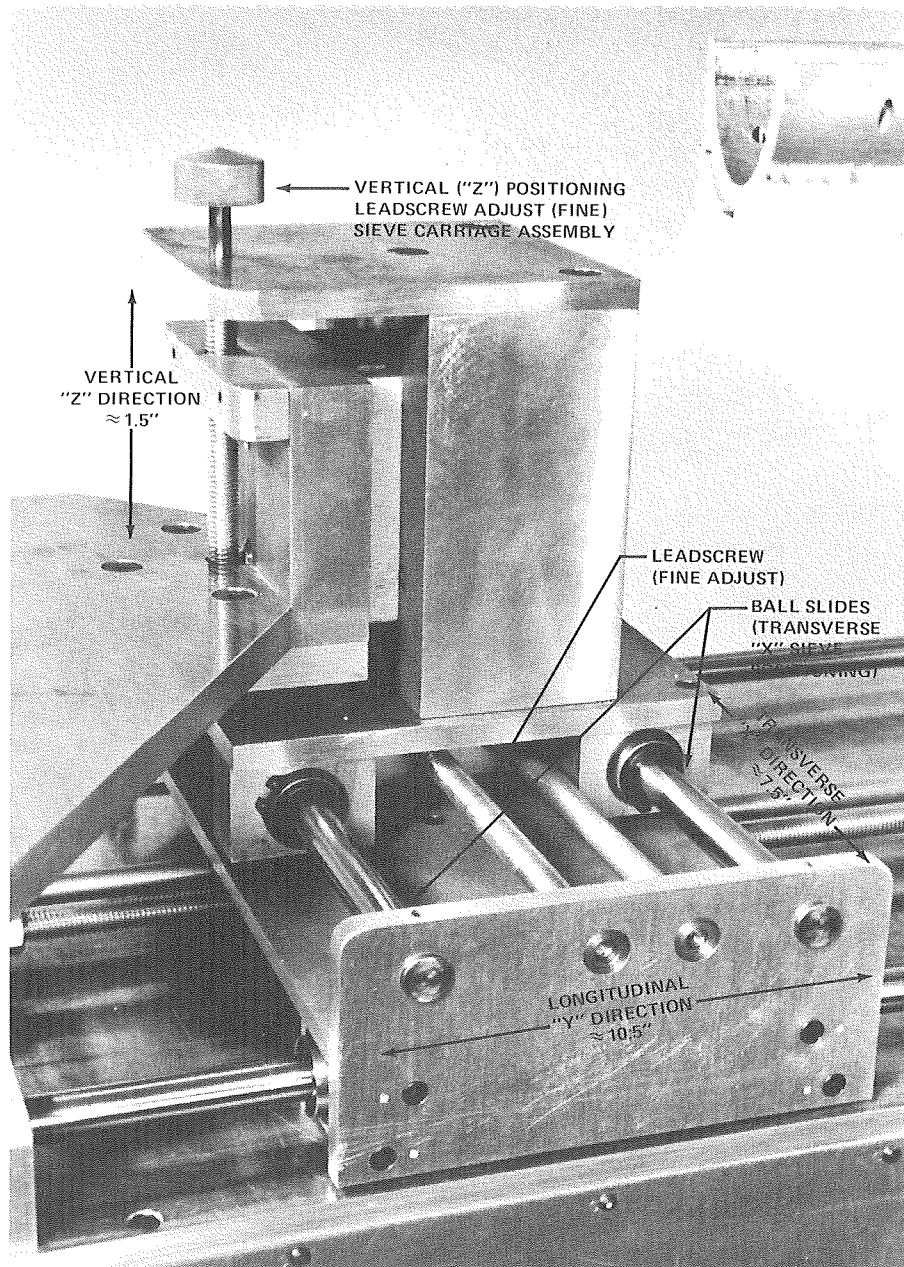


Figure 6B. Object Translator Carriage Assembly

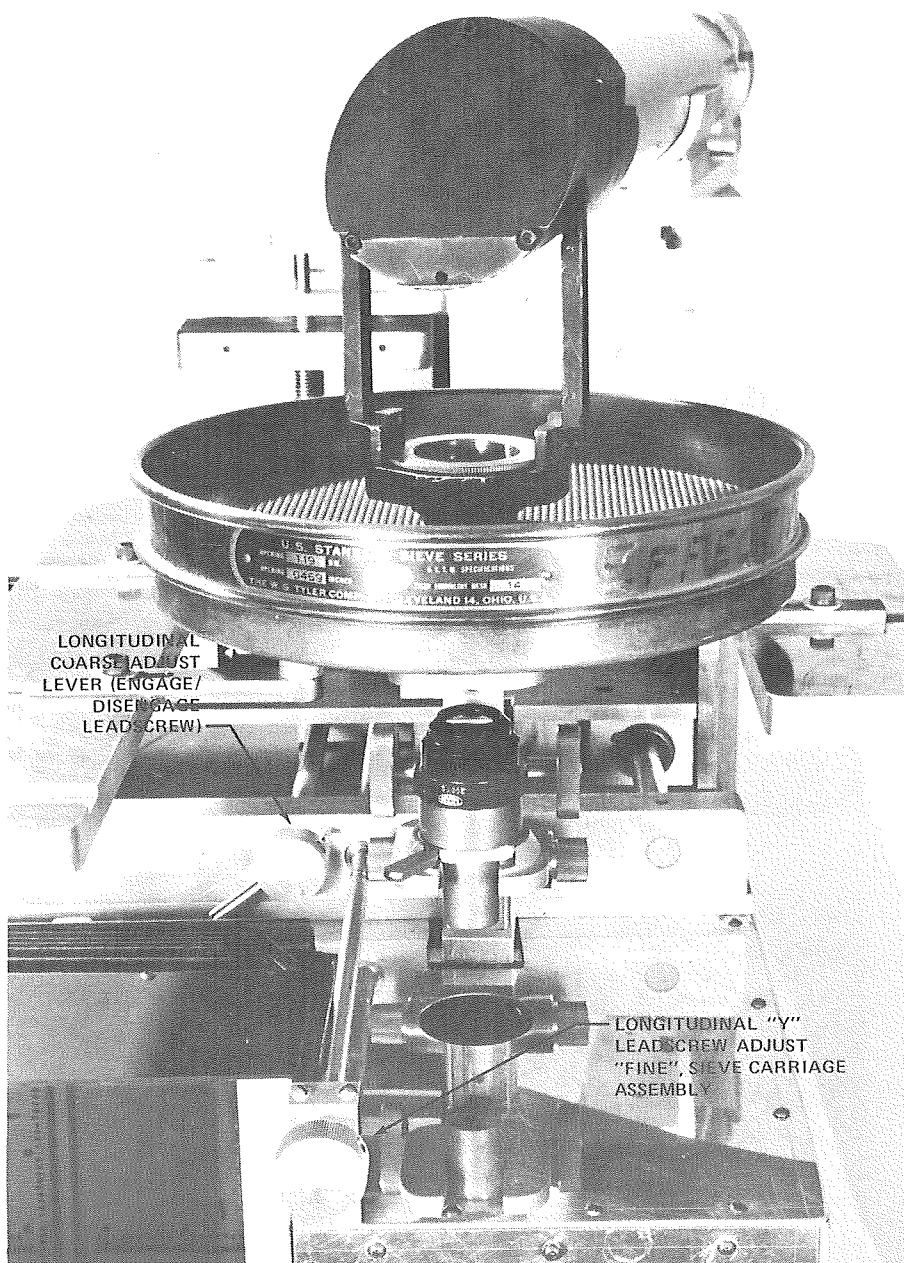


Figure 6C. Object Translator Carriage Assembly

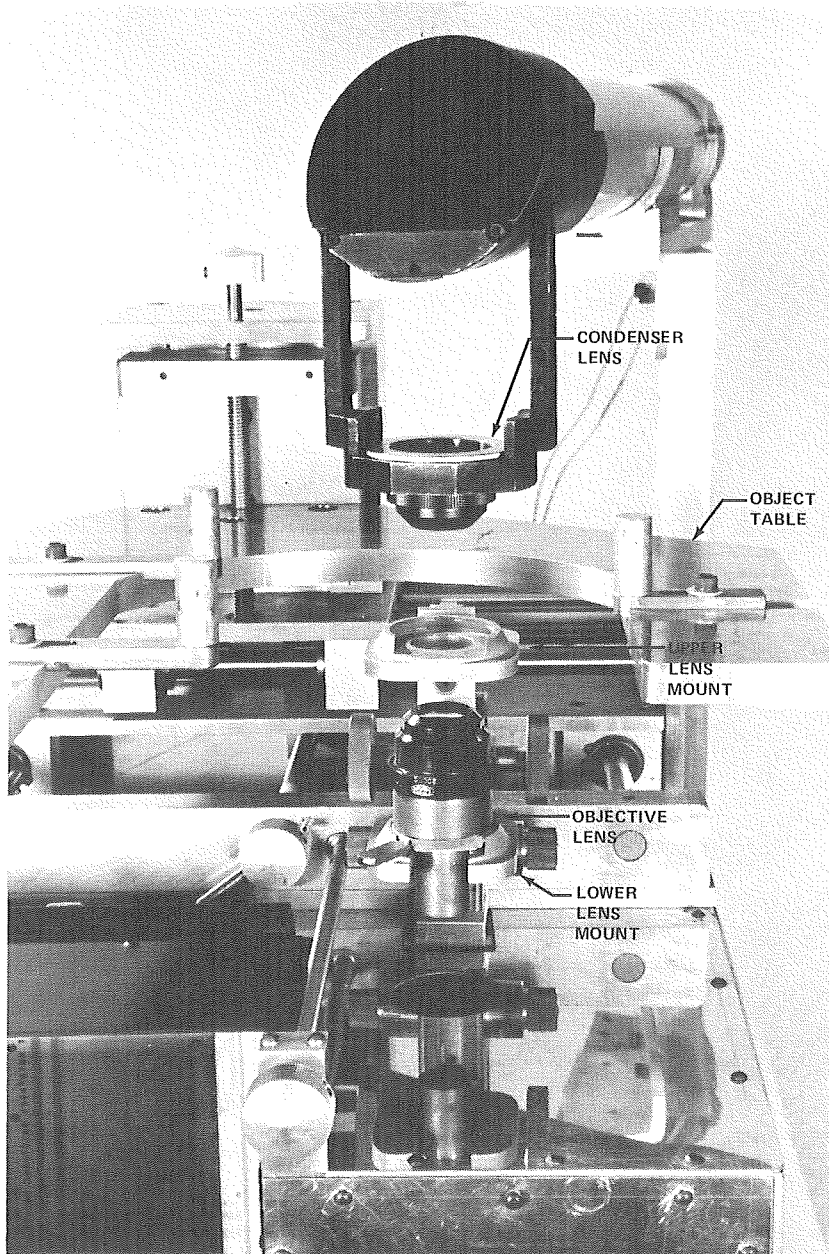


Figure 7A. Objective Lens Mount Assembly

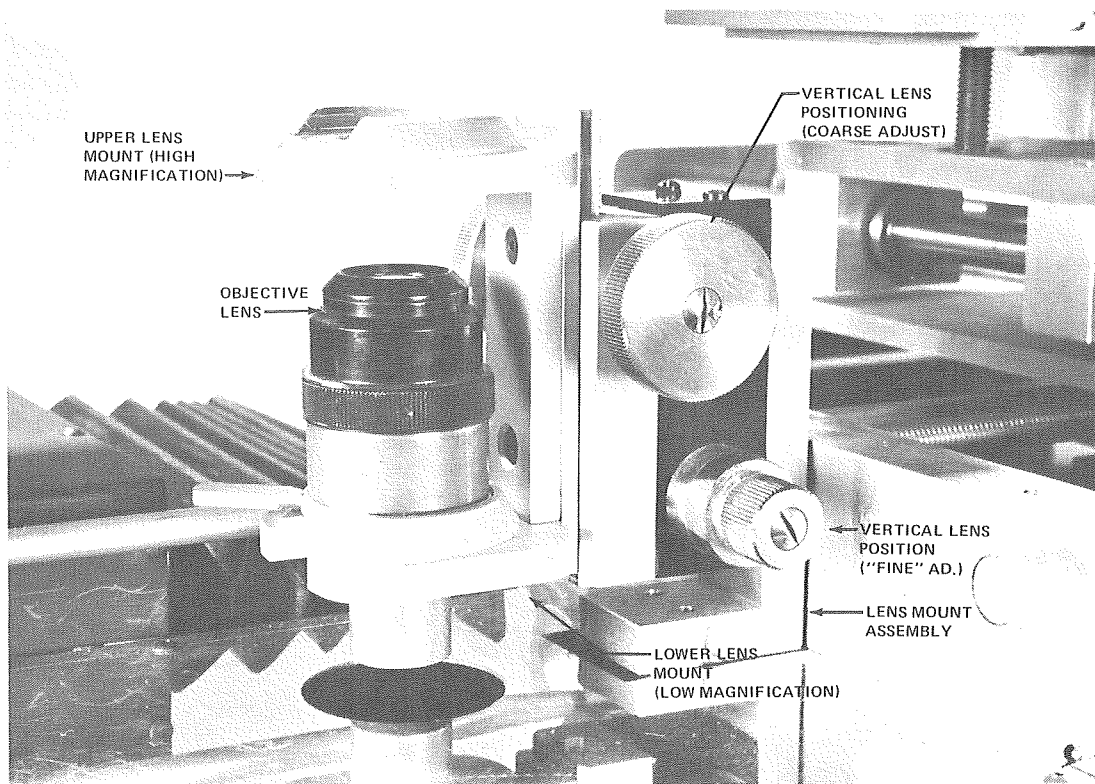


Figure 7B. Objective Lens Mount Assembly

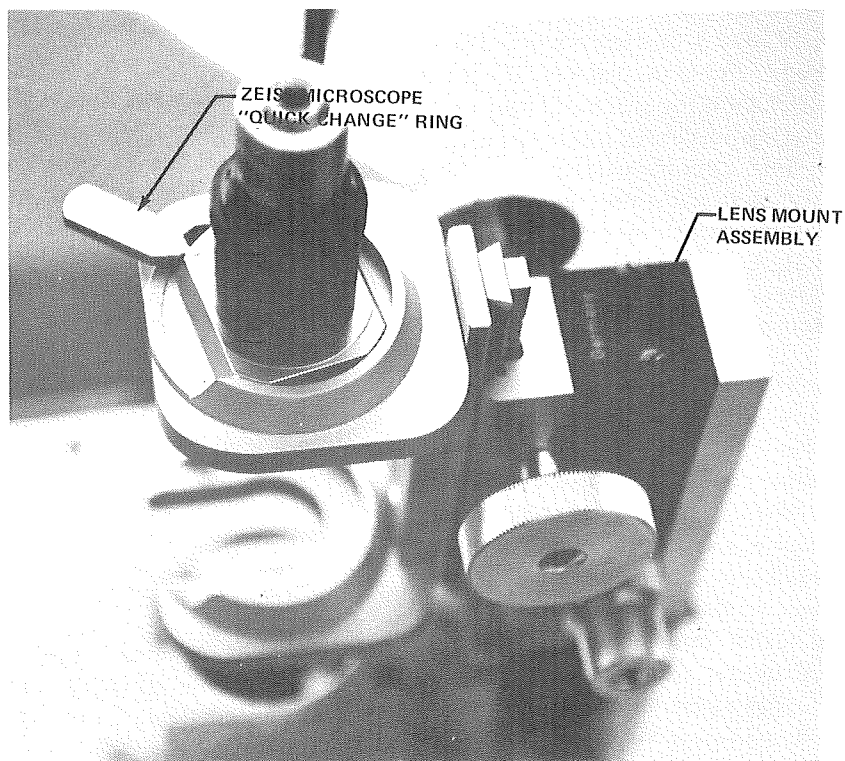


Figure 7C. Objective Lens Mount Assembly



high power lens, while the lower mount is used for the lower power lens. Each lens is fitted with a standard Zeiss microscope quick-change ring, which allows convenient insertion of the lens into the lens holder. The lens mount assembly contains a coarse and fine micrometer adjustment for vertically positioning the objective lens relative to the object — thus allowing precise focusing relative to the focal length of each individual lens. It should be noted that lens mount focus adjustments are used during system calibration only. Minor focus adjustments during sieve evaluation are made by vertically adjusting the sieve holder with the “Z” adjustment.

### **Illumination Assembly**

In order to obtain a bright image over the full magnification range of all objective lenses, a special collimated illumination system was required. The light system in use is basically a Kohler type illuminator\* designed to operate with three (3) different externally mounted condensing lenses. In this way, a correct numerical aperture is maintained for a high illumination efficiency. The illumination assembly is housed in a cylinder, 50mm inside diameter and 50cm long (Figure 5A). This configuration was chosen to conform with the relay lens requirements. A General Electric Quartzline (Tungsten-Halogen projection lamp) 80 watt, 19 volt lamp is positioned at one end of the cylinder. Three (3) relay lenses are internally mounted, with a 90 degree optical mirror mounted at the other end of the cylinder. The three (3) condenser lenses allow the collimated light to be sharply focused on the object for maximum illumination. Note that the illumination assembly (cylinder) is mounted to a pivoting bracket — thus allowing the assembly to be raised out of the way for changing sieves. A more detailed explanation of the illumination assembly will be presented in the Technical Description Section of this report.

### **Optical Chamber Assembly**

The optical chamber (Figures 5C and 5D) contains a transformer for the illumination system, a fixed 90 degree optical mirror directly beneath the objective lens mount, a 50 cm long optical V-rail and a mirror carriage onto which a pair of folding mirrors (180 degrees) are fixed. It should be noted that the V-rail and mirror carriage are standard commercially available items. The mirror carriage can be manually moved along the optical path, thus providing a “coarse” magnification adjustment.

At the front of the optical chamber is the viewing reticle receiver (Figures 5B and 8). The receiver is designed such that the various 6-inch square measurement and GO/NO GO viewing reticles can be clamped in place against a diffusion glass plate which is fixed within the receiver. The receiver is mounted to a commercially available micro-translation unit which provides “fine” magnification adjustment by moving the reticle image plane along the optical path (shortening or lengthening the optical distance). A standard photographic bellows provides a light-tight interface between the reticle receiver and the optical chamber.

### **Objective Lenses**

The ADOT comparator uses a set of five (5) microscope objective lenses, ranging from X3 to X40 in magnification (Figure 9). An aperture stop at the back focal plane of each lens makes the system telecentric. That is, the system magnification remains constant, independent of object focus. Table 2 lists the objective lenses and their range of magnification. Also listed is the “working distance” for each lens, that is, the average distance from the face of the lens to the object surface. This distance is an important factor when access to the object surface is restricted. Note that the X3 and X5 lenses are mounted in the lower lens mount socket, while the X10, X20 and X40 lenses use the upper socket.

### **Calibration Plate and Reticle**

System calibration is accomplished by use of a calibration object and a corresponding calibration viewing reticle (Figure 10). The calibration object is a Bausch & Lomb projection standard as used for pocket comparators. Two object standards are used with the ADOT comparator. One has 0.1 inch divisions, subdivided into 0.005 inch — the other having 1.0mm divisions, subdivided into 0.1mm.

The calibration viewing reticle (view plate) features two (2) scales (one horizontal and one vertical). See Figure 10. The scales are based on one (1) inch divisions, subdivided into 0.1, 0.025, and 0.005 inches. It should be noted that the calibration viewing reticle is *also* used for all absolute measurements during sieve evaluation.

The calibration plate is dimensioned such that the object standards are placed at the object reference plane corresponding to normal sieve measurements.

Calibration procedures will be covered in the System Calibration Section.

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\*Leo Levi, “Applied Optics,” Volume 1, John Wiley & Sons, New York, 1968, page 475.

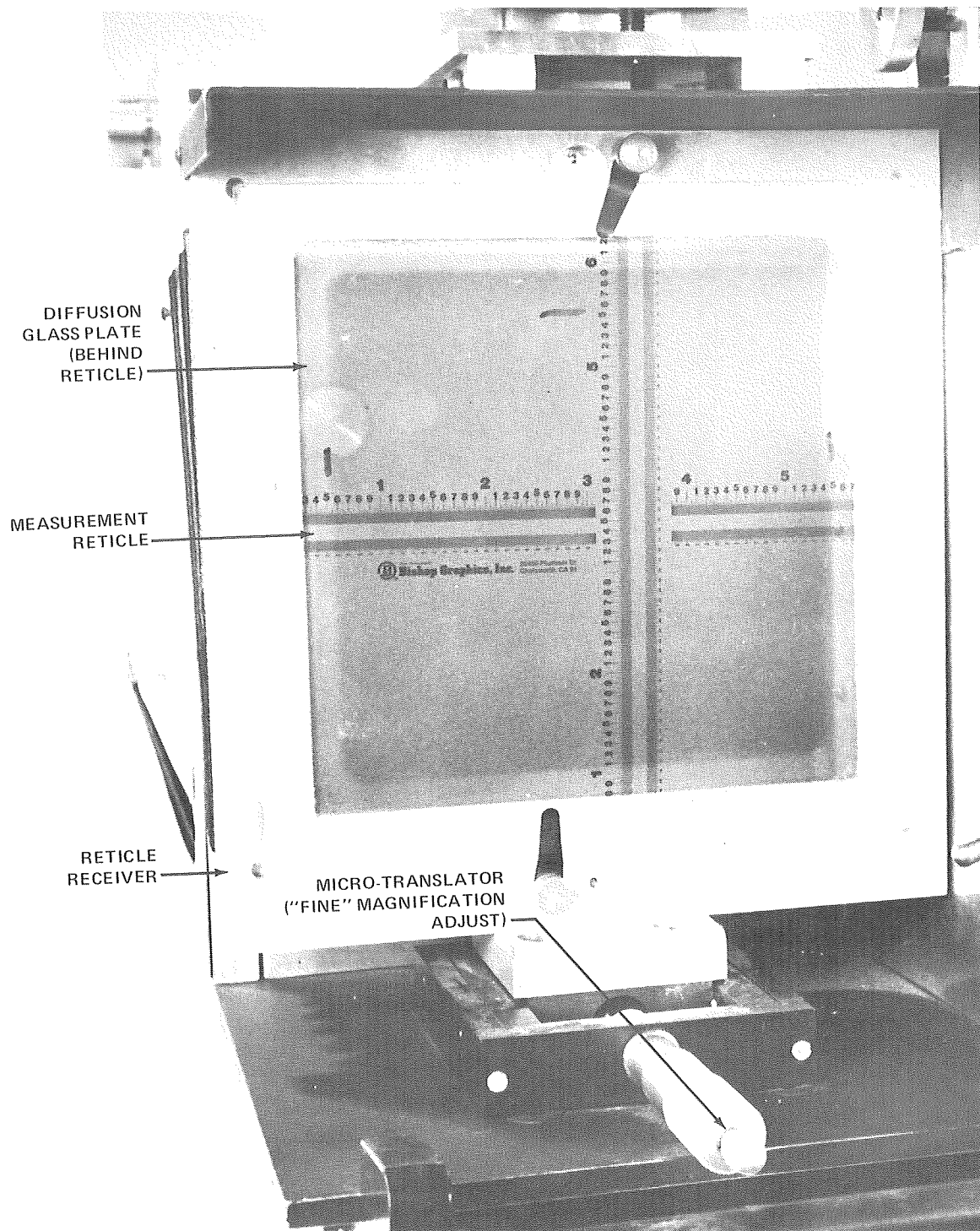


Figure 8. Viewing Reticle Receiver